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Growing maize in clumps as a strategy for marginal climatic conditions

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ABSTRACT

Under dryland conditions of the Texas High Plains, maize (*Zea mays*) production is limited by sparse and erratic precipitation that results in severe water stress particularly during grain formation. When plant populations are reduced to 2.0–3.0 plants m^{-2} to conserve soil water for use during grain filling, tillers often form during the vegetative growth and negate the expected economic benefit. We hypothesized that growing maize in clumps spaced 1.0 m apart would reduce tiller formation, increase mutual shading among the plants, and conserve soil water for grain filling that would result in higher grain yield. Studies were conducted during 2006 and 2007 at Bushland, TX. with two planting geometries (clump vs. equidistant), two irrigation methods (low-energy precision applicator, LEPA, and low-elevation spray applicator, LESA) at three irrigation levels (dryland, 75 mm and 125 mm in 2006; and dryland, 50 mm and 100 mm in 2007). For dryland plots in 2007, clump plants had only 0.17 tillers (0.66 tillers m^{-2}) compared with 1.56 tillers per plant (6.08 tillers m^{-2}) for equidistant spacing. Tillers accounted for 10% of the stover for the equidistant plants, but less than 3% of the grain. Clump planting produced significantly greater grain yields (321 g m^{-2} vs. 225 g m^{-2} and 454 g m^{-2} vs. 292 g m^{-2} during 2006 and 2007, respectively) and Harvest Indexes (0.54 vs. 0.49 and 0.52 vs. 0.39 during 2006 and 2007, respectively) compared with equidistant plants in dryland conditions. Water use efficiency (WUE) measurements in 2007 indicated that clumps had a lower evapotranspiration (ET) threshold for initiating grain production, but the production function slopes were 2.5 kg m^{-3} for equidistant treatments compared to 2.0 kg m^{-3} for clump treatments. There was no yield difference for method of irrigation on water use efficiency. Our results suggest that growing maize in clumps compared with equidistant spacing reduced the number of tillers, early vegetative growth, and Leaf Area Index (LAI) so that more soil water was available during the grain filling stage. This may be a useful strategy for growing maize with low plant populations in dryland areas where severe water stress is common.

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1. Introduction

Maize is one of the major irrigated crops in the Texas High Plains (Musick et al., 1990) with some of the highest mean county grain yields in USA (USDA-NASS, 2008), but has a large seasonal water requirement for maximum yields. Steiner et al. (1991) reported 683–785 mm of water use by a fully irrigated maize crop with a grain yield of 1150–1230 g m^{-2} at Bushland, TX. Lamm et al. (1995) conducted a study in northern Kansas and recorded 574–597 mm of seasonal water use by subsurface drip irrigated maize with maximum grain yields of 1050–1490 g m^{-2}. Howell et al. (1997) reported a maximum measured evapotranspiration (ET) rate of 12.4 mm day^{-1} for irrigated maize at Bushland, TX. In recent years, the area in maize production has increased due to high commodity prices for use in ethanol production in addition to its use feeding cattle and human consumption. The United States is the leading maize producer with 286 Gm^2 harvested area and production of 268.1 Tg, almost 40% of the world's production (National Agricultural Statistics Database, 2007). Dryland maize has been increasing in acreage in the Texas Panhandle and South Plains over the past few years. Bean (2007) reported that 17 100 ha of dryland maize was planted in the Northern and Southern Texas High Plains TASS (Texas Agricultural Statistics Service) districts during 2006 which was doubled compared to 2005 and had a higher average yield than grain sorghum. Apart from this, dryland maize pro-

Abbreviations: DAP, days after planting; PET, potential evapotranspiration; WUE, water use efficiency.

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Table 1
Average water use and precipitation from 1991 to 2006 during various growth stages of maize seeded on 15 May at Bushland (ARS), TX[¶].

Growth stages	Days	ETc (mm)	Precipitation (mm)	Pct./ETc (%)
Emergence	20 (14)[†]	47 (77)	35 (111)	73
10 leaf	39 (4)	247 (6)	81 (48)	33
Milk	35 (5)	292 (10)	72 (63)	25
Black layer	34 (8)	158 (11)	46 (85)	29
Total	128 (4)	745 (8)	233 (38)	31

[¶] *Source*: 15-year potential evapotranspiration (PET) data from Texas North Plains Evapotranspiration Network (2006).
[†] Numbers in parenthesis are coefficient of variation values.

duction increased more than 10 fold from 1995 through 2000 in semiarid western Nebraska (Blumenthal et al., 2003). The Texas High Plains are characterized by limited precipitation, low ambient humidity, and high evaporative demand due to high radiation, wind speed, and temperature that normally result in severe water deficit during the grain filling stage of the crop when irrigation water is not applied. An analysis of the water use and growing season precipitation for various maize growth stages at Bushland, TX, located in the North Texas High Plains, revealed that precipitation contributes a higher percentage of the potential crop evapotranspiration (ETc) (Table 1) during early vegetative growth stages compared to the milk and grain filling stages (Texas North Plains Evapotranspiration Network, 2006).

Several studies have been conducted to investigate the influence of plant population, row spacing, and planting geometries on the physiology and yields of maize. Babalola and Oputa (1981) studied seven plant populations of maize ranging from 2.4 plants m^{-2} to 7.3 plants m^{-2} by varying the row width and number of plants per hill in Nigeria. They found that grain yield increased with the increase in plant population from 2.4 plants m^{-2} to 5.4 plants m^{-2} but dropped beyond 5.4 plants m^{-2} due to early depletion of soil water. Noorwood (2001), under dryland conditions in Kansas, found that grain yield of maize increased with increased plant population from 3.0 plants m^{-2} to 4.5 plants m^{-2} but yield decreased with a plant population of 6.0 plants m^{-2}. While tiller formation is not considered a major problem with maize production when plant populations are generally in the range of 7.0 plants m^{-2} or greater, tillers are sometimes a concern at the lower plant populations used under dryland conditions. Nielsen (2003) reported that tillers can lead to reduction in grain yields and it was once common for farmers in the U.S. maize belt to remove tillers from maize plants. Many scientists and producers consider that tillers on maize plants do not have a negative effect on the ears on the main stalk (Thomison, 2003) when water is not limiting. However, in the Southern Great Plains, water is always a limiting factor for crop production under dryland conditions. Maize is increasingly being grown in marginal climatic regions where water deficit can be severe, particularly during the critical reproduction and grain filling growth stages. Under these conditions, farmers often reduce plant populations from 4 plants m^{-2} to 6 plants m^{-2} to 2.0 plants m^{-2} to 3.0 plants m^{-2} as a strategy to conserve soil water so that it is available for these critical growth periods. Under these low planting density conditions, maize plants often form one or more tillers during their early vegetative growth stages that use soil water and nutrients. However, these tillers usually do not contribute significantly to grain formation so the anticipate gain from using a low plant density is often reduced or negated. With increasing planting density more solar radiation is captured, space between neighboring plants is reduced, and competition for resources is increased. Blumenthal et al. (2003) reported that under dryland conditions of western Nebraska, maize grain yield increased 353 kg ha^{-1} with increasing plant population from 17 300 plants ha^{-1} to 27 200 plants ha^{-1} but increase of population beyond 27 200 resulted in inconsistent grain yields. Under dryland conditions, row width and available soil water influence the yields (Brown and Shrader, 1959). Water deficits during booting and flowering stages of grain sorghum (*Sorghum bicolor* (L.) Moench) resulted in 87% reduction in yield (Craufurd et al., 1993). Narrow row spacings increase shading, reduce evapotranspiration, and increase the competition between plants for water and light in the crop canopy (Baumhardt, 2004). Routley et al. (2003) found that skip-row configurations result in greater and more stable grain yields in sorghum under low yield levels by conserving the soil water in the center of the skip areas for use by the crop after anthesis. Similar results were found for skip-row configurations with maize in the central Great Plains (Lyon et al., 2009). Andrade et al. (2002) from Argentina reported increase in the maize grain yields by reducing the row spacing from 0.7 m to 0.52 m due to increase in radiation interception and decrease in plant-to-to competition for available water, nutrient and light.

Maize often uses stored soil water early in the growing season when conditions are favorable, and produces one to two tillers when plant populations are low, leading to high amounts of above-ground biomass and leaf area during early growth stages. Thomison (2009) observed that many maize hybrids will produce one or more tillers when the plant stands are thin by taking advantage of available soil nutrients and moisture during the first few weeks of the growing season. Bandaru et al. (2006) reported that planting grain sorghum in clumps reduced the number of tillers and vegetative growth, conserving more soil water until reproductive and grain filling stages that resulted in increased grain yield compared with uniformly spaced plants.

The hypothesis of this study was that growing maize in clumps spaced 1.0 m apart under dryland and minimal irigation would reduce tillers, increase mutual shading, and increase grain yield by conserving soil water for use during the grain filling crop growth stage when compared to uniform planting. The objective was to compare maize grown in clumps with uniformly spaced plants at the same populations under dryland conditions and with 50–125 mm of irrigation water added by low-energy precision application (LEPA) or low-elevation spray applicators (LESA). LEPA is a type of center-pivot irrigation system that was equipped with double-ended drag socks hanging down from a large water carrying pipes that apply water to the alternate rows and has the application efficiency of approximately 90–95%. LESA is same as LEPA except that instead of double-ended drag socks it has small water sprayers with nozzles very close to the ground that gently sprays water onto the crops with the application efficiency of 80–90%. Fully irrigated maize in the area normally receives 500–600 mm of irrigation water.

2. Materials and methods

Field experiments were conducted at the USDA-ARS Conservation and Production Research Laboratory in 2006 and 2007 at Bushland, TX (35°11′N, 102°5′W; 1180 m above mean sea level). The soil type was Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) containing 170 g kg^{-1} sand, 530 g kg^{-1} silt and 300 g kg^{-1} clay at 0–15-cm depth (Unger, 1999). The average long-term annual precipitation at Bushland is 470 mm with an

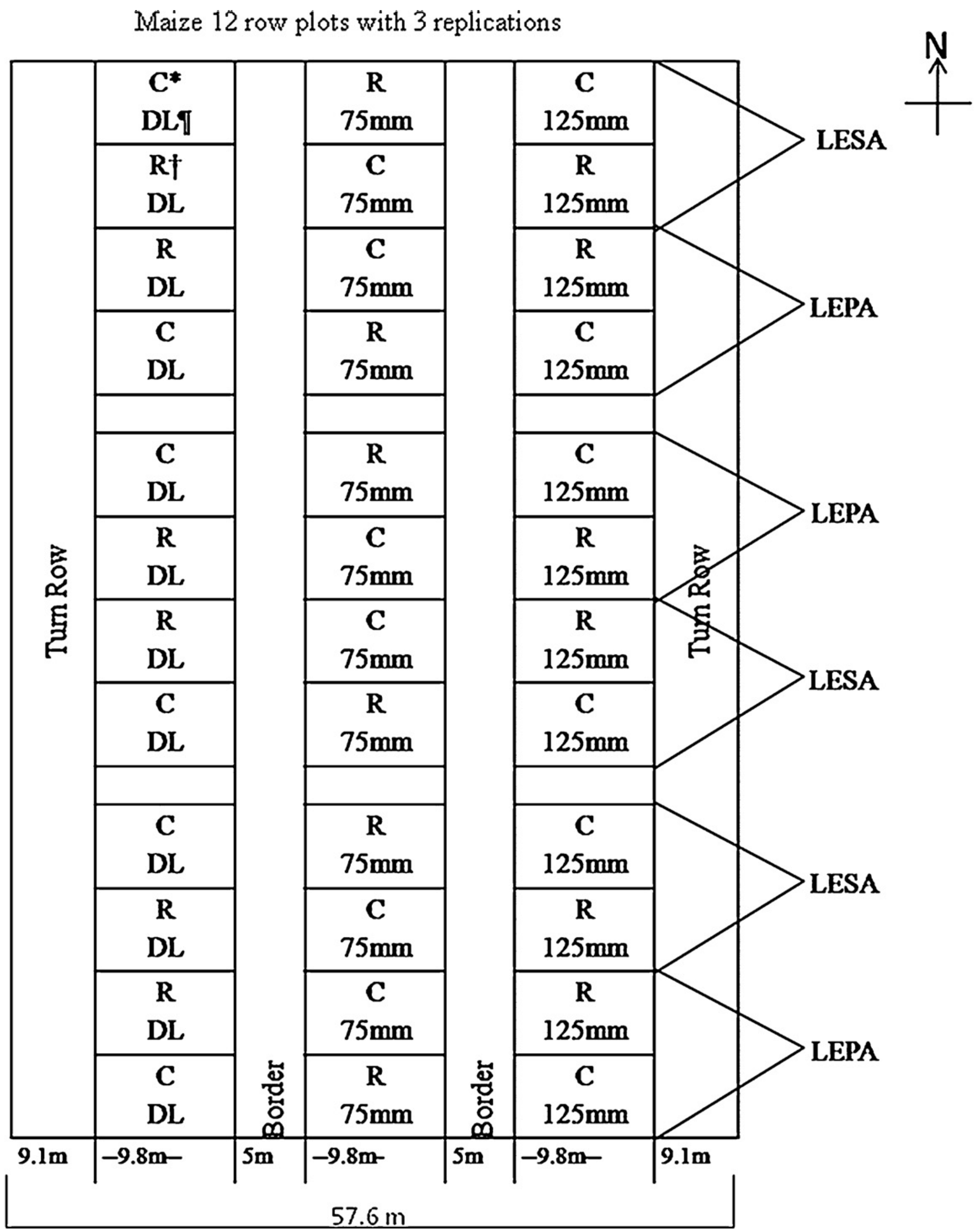

Fig. 1. Plot layout for maize study at Bushland, TX, 2006. *C: clump; †R: rows; ¶DL: dryland.
Note: For 2007 study, plot layout remained the same except the irrigation levels of 75 and 125 mm changed to 50 and 100 mm, respectively.

average annual potential evapotranspiration of 1880 mm (Stewart, 1988).

2.1. 2006 Experiment

Maize planted in clumps was compared with uniformly spaced plants in a strip block design. The irrigation methods (strips running from East to West) and planting geometries (blocks) under three water levels were the treatments considered with three replications (Fig. 1). LEPA and LESA were the two irrigation methods used to compare their effect on maize growth and yield. A lateral move irrigation system was used (Colaizzi et al., 2004). The LEPA system was equipped with double-ended drag socks to apply the water to alternate rows and the LESA system applied water at a height of 30-cm above the soil surface. In general, the LEPA system resulted in wetting alternate furrows while the LESA wetted the entire soil surface area. The plant population was 3.9 plants m^{-2} and was targeted to 3 plants clump^{-1} every 102 cm along 75-cm rows. In the conventional row plots, plant population was targeted to have uniformly spaced plants (34 cm) in 75-cm rows. Rows were oriented East–West, and the irrigation system traveled parallel to the row direction.

The three irrigation levels were 0 mm (dryland), 75 mm and 125 mm. An additional unplanned irrigation (25 mm) was applied

Table 2
Growing season climatic data at Bushland, TX.

Month	Precipitation (mm)	Avg. precip.[†] (mm)	Avg. temp. (°C)	Reference ET[‡] (mm)
2006				
May	17	68	20	234
June	29	75	25	272
July	62	68	26	230
August	98	72	23	176
September	32	49	17	126
October	43	39	13	111
2007				
May	40	68	17	162
June	56	75	21	194
July	36	68	24	207
August	63	72	24	201
September	42	49	20	150

† Average precipitation amounts are mean values for 58 years at Bushland (Unger, 2001).
‡ Reference evapotranspiration (ET) values for Bushland represent amounts of water a well-watered grass crop used (Texas North Plains Evapotranspiration Network, 2006).

Table 3
Mean values of ears, kernel mass, grain yield and HI for maize as affected by two planting geometries and three water levels at Bushland, TX, in 2006 at a density of 4 plants m^{-2}.

Irrigation rates	Planting geometry	Ears m^{-2}	Kernel mass (mg)	Grain yield ($g\,m^{-2}$)[¶]	Harvest Index[†]
Dryland (0 mm)	Clump	3.7 a[‡]	229 a	326 a	0.54 a
	Row	3.6 a	206 b	228 b	0.48 b
75 mm	Clump	3.7 a	276 a	431 a	0.53 a
	Row	3.8 a	233 b	339 a	0.47 b
125 mm	Clump	3.7 a	308 a	510 a	0.56 a
	Row	3.6 a	258 b	404 b	0.50 a

‡ Grain yield reported at 15.5% moisture level (wet basis).
¶ Harvest Index based on dry weight of grain divided by dry weight of aboveground biomass.
† Numbers followed by same letter are not significantly different ($P \le 0.05$) within an irrigation rate.

Table 4
Mean values of measurements for maize as affected by two planting geometries and three water levels at Bushland, TX, in 2007 at a density of 4 plants m^{-2}.

Irrigation rates	Planting geometry	Total grain yield[¶] ($g\,m^{-2}$)	Tiller grain yield[¶] ($g\,m^{-2}$)	Total number of ears (# m^{-2})	Tiller ears (# m^{-2})	Total aboveground biomass (at harvest) ($g\,m^{-2}$)	Tillers aboveground biomass (at harvest) ($g\,m^{-2}$)	Kernel mass (mg)	Harvest Index[†]
Dryland	Clump	461 a[‡]	1.8 a	4.09 a	0.41 a	743 a	9.7 b	241 a	0.52 a
	Rows	297 b	1.5 a	4.52 a	0.44 a	643 b	52.1 a	224 b	0.39 b
50 mm	Clump	547 a	6.2 a	5.02 a	0.74 b	973a	43.9 b	272 a	0.47 a
	Rows	465 b	9.6 a	5.17 a	1.31 a	806b	81.7 a	256 b	0.49 a
100 mm	Clump	703 a	5.9 a	4.59 b	0.62 b	1142 a	25.6 b	287 a	0.52 a
	Rows	621 b	20.7 b	6.10 a	1.65 a	1037b	104.9 a	293 a	0.51 a

¶ Grain yield reported at 15.5% moisture level (wet basis).
‡ Harvest Index based on dry weight of grain divided by dry weight of aboveground biomass.
† Numbers followed by same letter are not significantly different ($P \le 0.05$) within an irrigation rate.

to all the plots on 6 June to enhance germination since soil conditions were exceptionally dry. Each plot was 10 m long and had twelve 75-cm rows. Water treatments were separated by a 5-m border area to avoid water application rate overlap as the system speed was manually adjusted to apply the desired application rate. Turn rows (9 m long) were on both ends of the plot area. Border rows (5 m long) were between the two strips, but turn rows and borders around the study area were not planted. Field preparation was tandem disking, bedding with a disc-bedder, and followed by running a rolling cultivator and culti-packer over the rows. A pre-plant soil analysis showed 7.8 $g\,m^{-2}$ NO_3-N present in the soil. Based on an assumption of a potential maize yield level of 630 $g\,m^{-2}$, 2.7 $g\,m^{-2}$ of N was added. This was added in two applications of urea-enriched irrigation water on 19 and 26 April when 25 mm pre-plant irrigations were applied to partially wet the soil profile before planting.

Maize was seeded on 3 May with short-season hybrid (Pioneer[3] 38H65) using a two row John Deere 71 Flex planter modified to drop three seeds simultaneously per 102 cm along four 75 cm rows in clump plots. A six-row John Deere Max Emerge planter was used with different plates for seeding single seeds in the conventional row plots. The planter was set to drop one seed approximately every 34 cm in the rows. Furrow diking was done in all the plots 33 days after planting (DAP).

Soil water content was determined gravimetrically at 30-cm increments to 1.8-m depth at seeding as well as at harvest using

[3] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or West Texas A&M University.

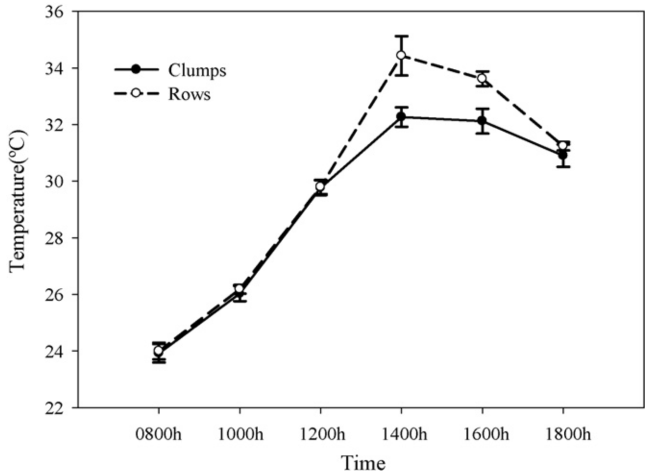

Fig. 2. Comparison of maize leaf temperatures between clumps and uniformly spaced plants under dryland conditions on 2 July, 2006 (59 DAP), at Bushland, TX. *Note*: Leaf temperature is averaged over three measurements at same time on same day.

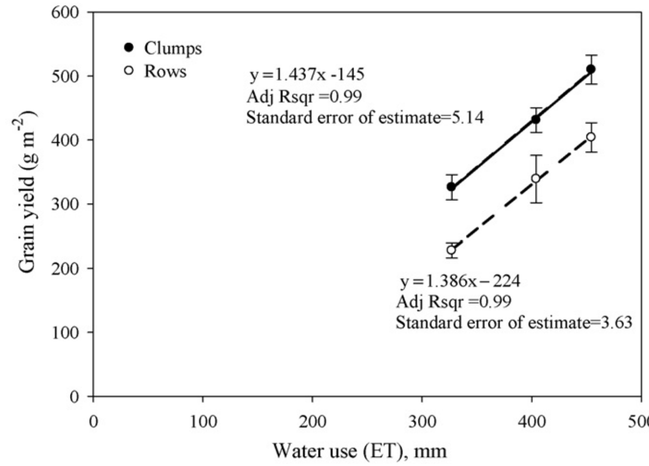

Fig. 4. Relationship of maize grain yield† to seasonal water use‡ for dryland, 75 mm and 125 mm irrigation in 2006.
‡Total water use (ET) were obtained by adding change in soil water content which was estimated by taking the average of soil water content from all the plots by gravimetric method on the day of sowing and after harvest plus precipitation and irrigation.
†Grain yields were reported at 15.5% moisture level (wet basis).

a tractor-mounted hydraulic soil sampler on all 36 plots. Water content was expressed on volumetric basis by using previously determined soil bulk density values.

At harvest, aboveground biomass and grain yields were determined from four clumps in clump plots and 4 m of row plots. This represented 3 m^2 for both planting geometries. The plants for harvesting were selected and tagged shortly after emergence within the four middle rows making sure that each set of selected plants was surrounded by plants of uniform stand. Samples were oven-dried at 60 °C for 1 week and then weighed to obtain biomass and threshed to measure grain mass. Grain yield was reported at 15.5% moisture (wet basis).

Leaf canopy temperatures were measured on 2 July, 59 DAP, a hot sunny day, on three plants per plot at two-hour intervals between 0800 h and 1800 h. A hand-held infrared thermometer (Raytek Corp., Model RAYST3U, Santa Cruz, CA) was pointed to the lamina of the upper most fully emerged leaf from south towards north at an altitude angle of 45° so that only plant parts were viewed.

Measurements were sorted “by irrigation rate” and analyzed using the General Linear Models MANOVA procedure from Statistical Analysis System software (SAS, version 9.1.3). Treatments and replications were considered as fixed and random effects, respectively. Mean separation of fixed effects was performed using the “lsmeans” option with Tukey’s multiple comparison adjustment at $P < 0.05$ significance level.

2.2. 2007 Experiment

The experimental design, number of treatments, methodology of implementing the experiment, and data analysis were the same as for 2006, except the irrigation levels were 0 mm (dryland), 50 mm and 100 mm because of the higher rainfall during 2007 compared to 2006. Plots were seeded on 17 May with the same short-season hybrid used in 2006. Clump plots were planted using the two-row John Deere 71 Flex planter and uniformly spaced plots were planted using the six-row John Deere Max Emerge planter following the same method as described in the 2006 study. Experimental design remained the same.

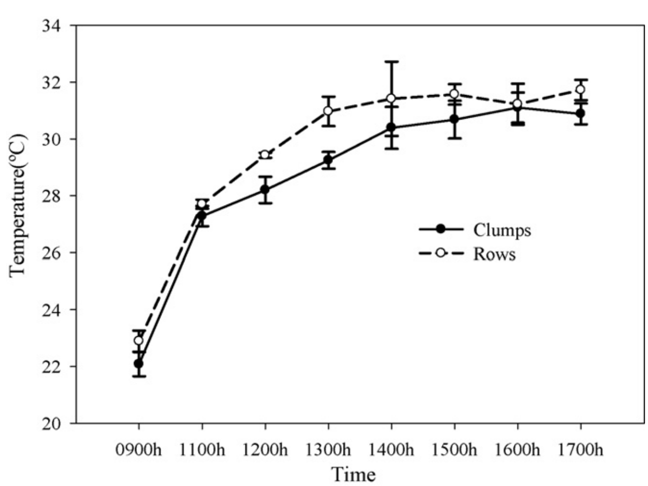

Fig. 3. Comparison of hourly maize leaf temperature between clumps and equidistant plants on 10 July, 2007 (54 DAP) at Bushland, TX.

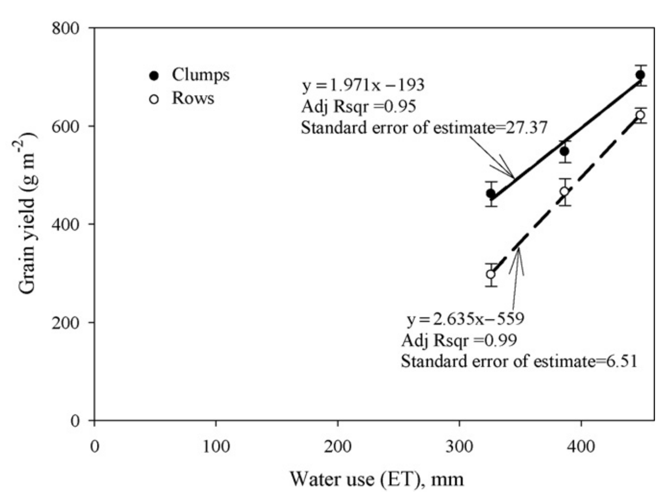

Fig. 5. Relationship of maize grain yield† to seasonal water use‡ for dryland, 50 mm and 100 mm irrigation in 2007.
‡Total water use (ET) were obtained by adding change in soil water content which was estimated by taking the average of soil water content from all the plots by gravimetric method on the day of sowing and after harvest plus precipitation and irrigation.
†Grain yields were reported at 15.5% moisture level (wet basis).

Table 5
Mean values of water use (evapotranspiration) and grain yield of maize as affected by two planting geometry and three water levels at, Bushland, TX, in 2006 and 2007 at density of 4 plants m^{-2}.

Irrigation rates	Planting geometry	Water use (ET) (mm)		Grain yield[¶] ($g\,m^{-2}$)	
		2006	2007	2006	2007
Dryland	Clumps	327	326	326	461
	Rows	327	326	228	297
50 mm	Clumps	404	386	431	547
	Rows	404	386	339	465
100 mm	Clumps	454	448	510	703
	Rows	454	448	404	621

[¶] Grain yield reported at 15.5% moisture level (wet basis).

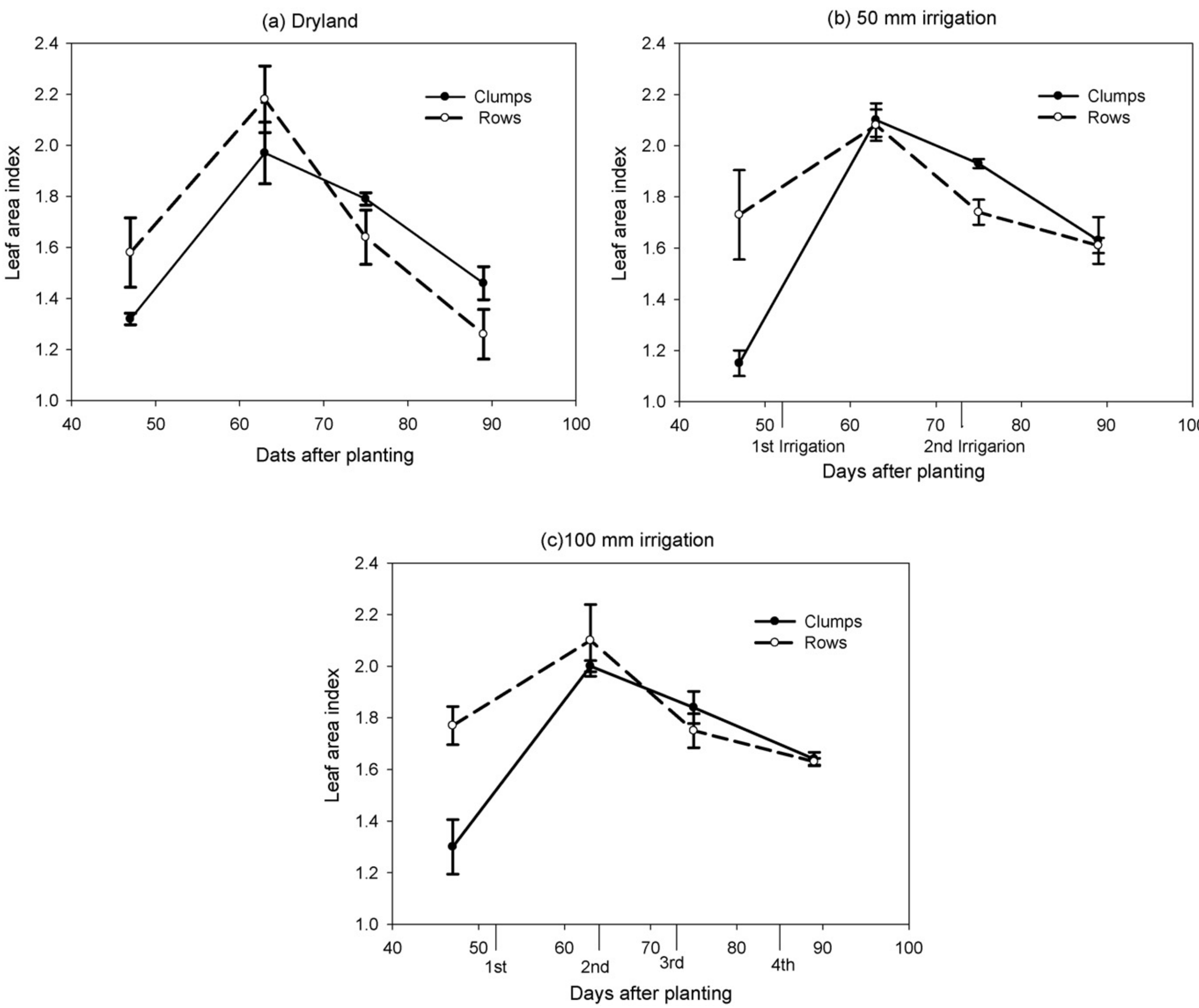

Fig. 6. Comparison of maize Leaf Area Index (m^2/m^2) of clumps and evenly spaced plants under (a) dryland, (b) 50 mm irrigation and (c) 100 mm irrigation[†] at 47, 63, 75 and 89 days after seeding, Bushland, TX, in 2007.
[†]1st, 2nd, 3rd and 4th represent the day of irrigation and was 25 mm.

Soil water content was determined gravimetrically at seeding as well as at harvest on all 36 plots as for 2006. In addition, soil water measurements were made at different crop growth stages using a neutron probe by installing tubes to a depth of 2 m, placed half-way between two plants within rows (17 cm from a plant) and two access tubes in clump rows with one tube 17 cm from a clump and the second at the midpoint between clumps (50 cm). Therefore, the tubes were installed at the same distance away from plants in the clumps and row plots. Soil water measurements were taken only from the LESA irrigated plots because it was assumed there would be more uniform horizontal distribution of irrigation water throughout the plots as compared with the LEPA plots that had alternate furrow wetting.

No fertilizer was applied since the crop was planted on fallowed area. Weeds were controlled by hand hoeing. Excess plants were thinned 14 days after planting from the row plots to establish a sim-

Table 6
Mean values of tillers and number of leaves for maize as affected by two planting geometries and three water levels at Bushland, TX, in 2007at a density of 4 plants m^{-2}.

Irrigation rates	Planting geometry	Tillers $plant^{-1}$	Number of leaves (74 DAP[¶])		
			Main stalk	First tiller	Second tiller
Dryland (0 mm)	Clump	0.22 a[‡]	16.7 a	11.0 a	0 b
	Rows	1.56 b	17.3 b	11.1 a	8.7 a
50 mm	Clump	0.44 a	16.8 a	13.0 a	0 b
	Rows	1.33 b	16.6 a	10.2 a	9.1 a
100 mm	Clump	0.17 a	16.6 a	0.0	0 b
	Rows	1.39 b	17.4 b	11.4 b	7.5 a

‡ Days after planting.
¶ Numbers followed by same letter are not significantly different ($P \leq 0.05$) within an irrigation rate.

ilar plant density for the clumps and row plots with three plants for every meter of row. Irrigation was applied 53, 64, 74 and 83 days after planting according to the treatments planned and each irrigation was equal to 25 mm. Tiller number and numbers of leaves on primary and secondary tillers were determined on three randomly selected adjacent plants within the middle four rows of the plots in the uniformly spaced plants and one clump having 3 plants $clump^{-1}$ in the clump plots at different growth stages of the crop. Leaf Area Index (LAI) was determined 47, 63, 75 and 89 DAP on plants from dryland and LESA irrigated plots by destructive plant sampling because soil water was measured on LESA irrigated plots and determining leaf area measurements for all the plots was not feasible. For uniformly spaced plants within the row, three contiguous plants (1 m of row) were collected as one sample. One clump was collected from each LESA clump plot. Leaf area was measured using a leaf area meter (LI-COR Corp., model 3100, Lincoln, NE).

Grain yield, number of ears, and Harvest Index (HI) were determined by harvesting 2.25 m^2, 9 plants (3 m) from the conventional row plots and 3 clumps having 3 plants $clump^{-1}$ from clump plots. Samples were oven-dried at 60 °C for 1 week and then weighed to obtain biomass and threshed to measure grain mass. Grain yield was reported at a 15.5% moisture (wet basis) level. On 10 July, leaf temperatures were measured at hourly intervals between 0900 h and 1700 h (Central Standard Time) at 11th leaf stage in the same manner as described for the 2006 study.

The data were analyzed using Proc GLM for SAS software (Version 9.1.3) as described in the 2006 study.

3. Results and discussion

3.1. Weather

Weather conditions during 2006 were not favorable compared to 2007 at early growth stages of the crop (Table 2). Very low precipitation amounts of 17 mm and 29 mm during May and June coupled with high temperatures resulted in severe water deficits in 2006. Precipitation during August was much above average and the total received for the growing season was 240 mm. The growing season precipitation during 2007 was 203 mm, and although this was 30 mm less than the long-term average, the timely distribution resulted in higher grain yields than the previous year.

3.2. Grain yield

For 2006, results for grain yield and yield parameters (Table 3) from the sampled areas (3.0 m^2 area for each plot) showed no significant ($P = 0.05$) effect on number of ears m^{-2} with respect to planting geometry at all water levels. However, there was significantly ($P = 0.05$) higher average kernel mass for clump planting geometry compared with uniformly spaced plants in conventional rows for all water levels (Table 3). Due to abundant precipitation in August and September 2006, plant available soil water was not limited during the grain filling stages. However, grain yields were 42%, 26% and 26% greater for the clump planting compared with those of the uniformly spaced plants under dryland, 75 mm and 125 mm irrigation levels.

During 2007, clump planting yielded 55% more grain than the uniformly spaced plants under dryland conditions (Table 4). At 50 mm and 100 mm irrigation, clump planting produced 13% and 17% significantly greater grain yield, respectively, compared with uniformly spaced planting. A major factor for the higher grain yield for the clump treatment was the higher HI. Further, significantly greater kernel mass was developed with the clump geometry under dryland and the 50 mm irrigation treatments compared with the conventional rows.

3.3. Harvest Index (HI)

The HI values were significantly ($P = 0.05$) greater for the clump treatment compared with conventional, uniform plant spacing under the dryland treatment and the 75-mm water level treatment during 2006 (Table 3) and under dryland treatment during 2007 (Table 4) indicating that more of the biomass was allocated to grain production in clump planting geometry. Studies of Prihar and Stewart (1990) showed that environmental stress causes reduction in the HI values in sorghum. Results for HI values from this study support the hypothesis that clumped plants result in higher HI values and experience lower environmental stress than equally spaced plants grown in water-limited environments.

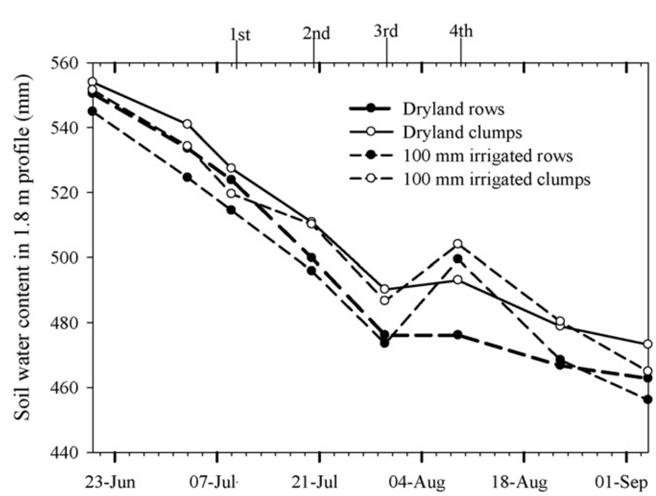

Fig. 7. Soil water content in the 1.8 m profile in dryland and 100 mm LESA method of irrigated maize (1st, 2nd, 3rd and 4th represents the day of irrigation with each irrigation as 25 mm), Bushland, TX, in 2007.

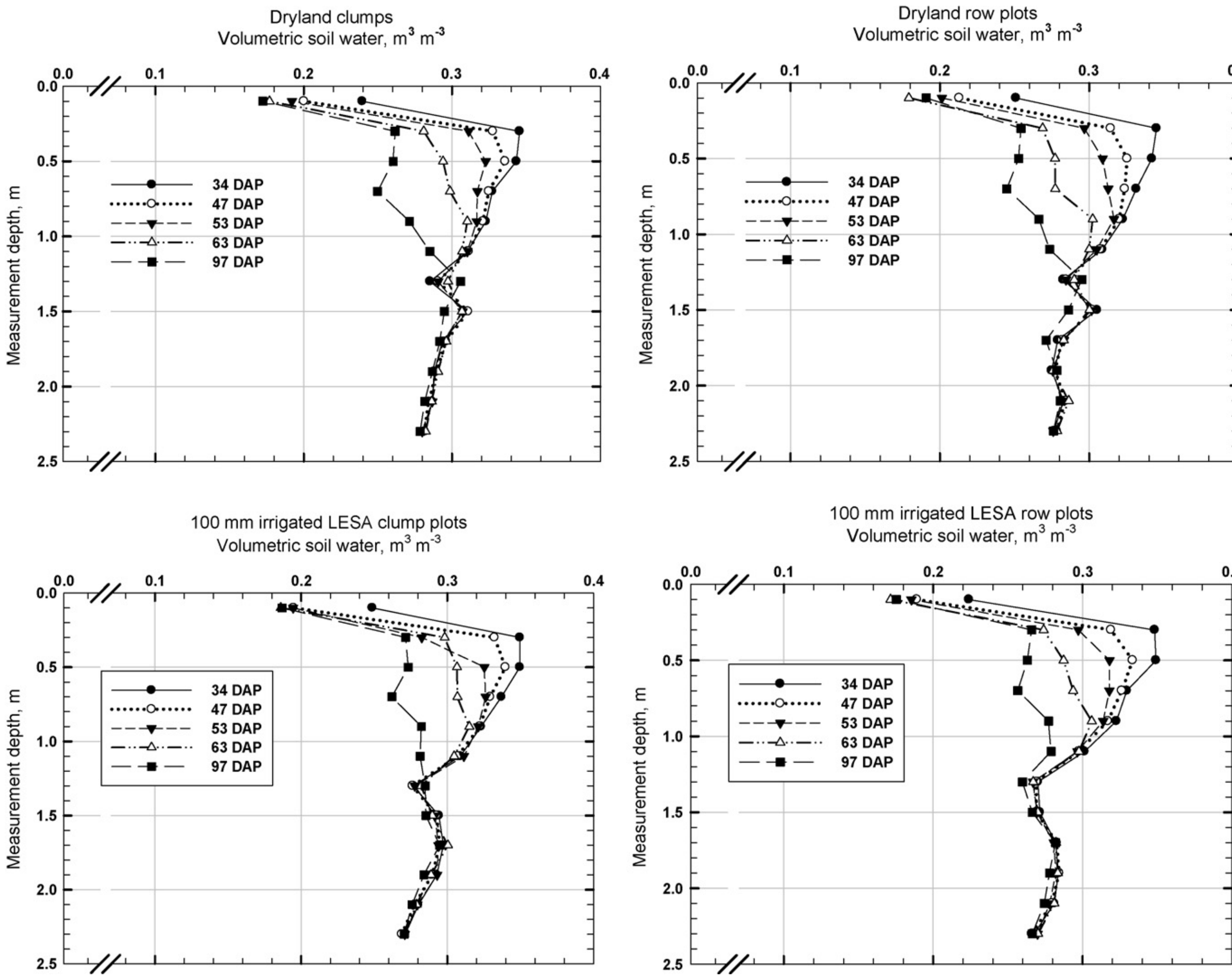

Fig. 8. Comparison of volumetric soil water content in the 2.4 m profile between clumps and evenly spaced plants under dryland and 100 mm irrigated LESA treatments at different stages of plant growth, Bushland, TX, in 2007.
Note: Volumetric soil water contents were calculated by averaging the soil water values obtained from six neutron access tube locations which were placed half-way between two plants within rows and two access tubes in each clump plot of which one was 17 cm from a clump and the second was 50.8 cm from the clumps.

3.4. Leaf temperatures

The greater leaf canopy temperature for the uniformly spaced plants may be indicative of less available soil water than for the clumped plants, or a higher percentage of the leaves receiving direct radiation. Leaf temperature measurements made on 2 July in 2006 (Fig. 2) and 10 July in 2007 (Fig. 3) showed that equidistant plants were ∼2 °C warmer than clumped plants during the hottest part of the day indicating that they were under greater water deficit conditions. Many studies have shown that leaf temperatures increase during the day as a function of increasing water deficits (Van Bavel and Ehrler, 1968; Jackson et al., 1977). Under water deficit conditions, stomata close and increase the leaf temperatures (Aston and Van Bavel, 1972). Water deficits symptoms were visually observed a few days earlier during the growing season for equidistant treatments than for the clump treatments.

3.5. Seasonal water crop use

Grain yield as a function of seasonal water use during 2006 and 2007 is illustrated in Figs. 4 and 5, respectively, and Table 5. The production functions indicate threshold values of 101 mm and 162 mm water use during 2006 and 98 mm and 212 mm water use during 2007 were required for initiation of grain production for clump treatments and equidistant spaced treatments, respectively. For both years, the clump treatment had a significantly lower threshold requirement for initiating grain production. However, it is less clear regarding how grain yield is affected by additional amounts of evapotranspiration. For each additional mm of water use by equidistant plants in 2006, grain yield was increased 1.37 kg m^{-3} compared to 1.43 kg m^{-3} for clumped plants (Fig. 4). During 2007, increases in the grain of 2.0 kg m^{-3} for clumps and 2.5 kg m^{-3} for row treatments were indicated for each mm of additional water use after meeting the threshold water use level (Fig. 5). The production function slopes of the present study are similar to the 2.45 kg m^{-3} production function proposed by Howell et al. (1995), and the same as the 2.6 kg m^{-3} reported for maize in northeastern Colorado (Nielsen, 1995, 2006). Lamm et al. (1995) reported the increase of 0.048 Mg $ha^{-1}$of maize grain yield for each millimeter of water used above a threshold of 328 mm. The threshold water use level was lower for clumps compared with row treatments indicating that clump planting produced greater grain yield

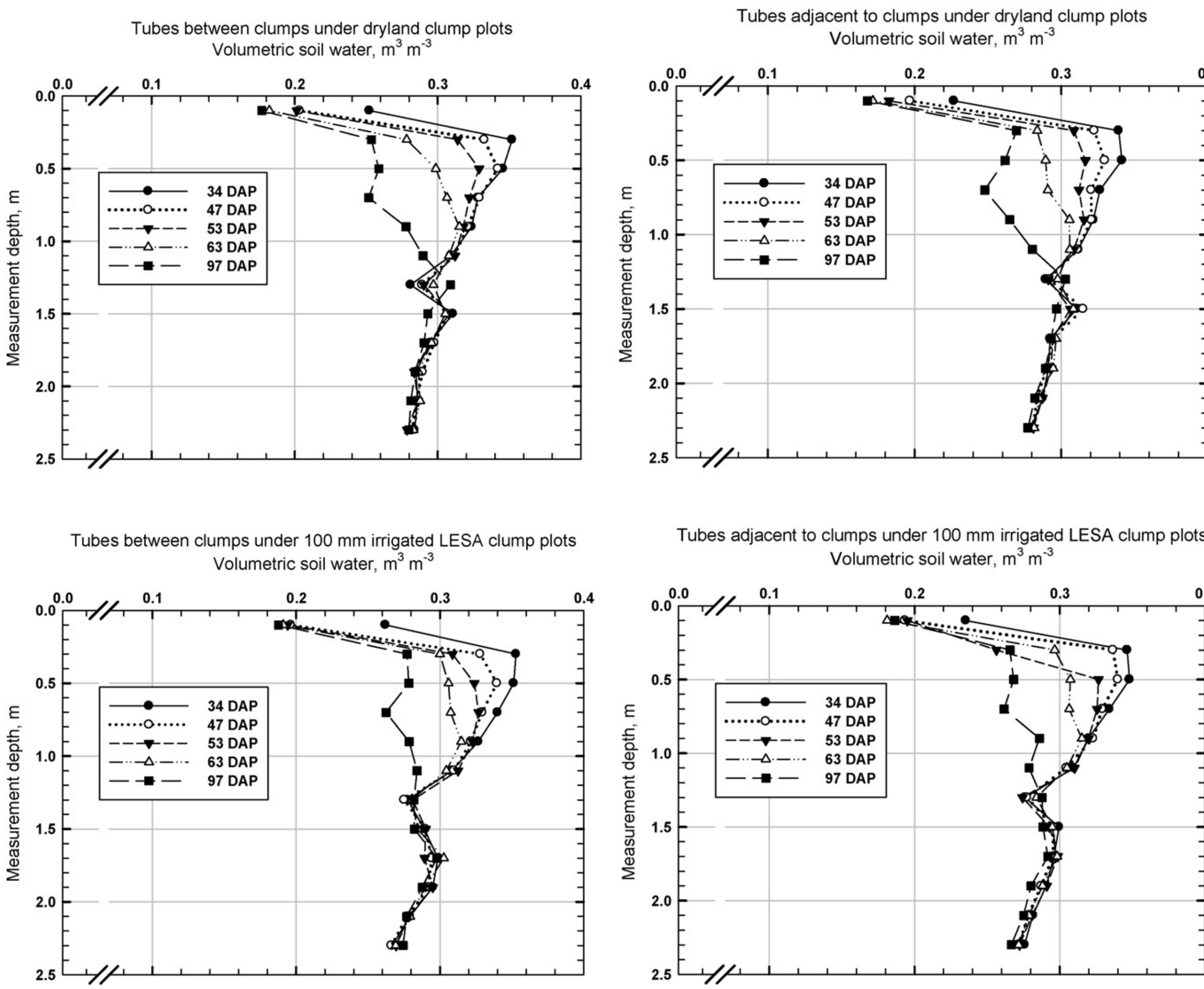

Fig. 9. Comparison of volumetric soil water content in maize between the tubes which are placed half-way (50.8 cm form each clump) between two clumps and adjacent tubes which are placed 17 cm from a clump under dryland and 100 mm irrigated LESA treatments at different stages of crop growth, Bushland, TX, in 2007.

with lower water use compared with evenly planted maize. Under limited soil water, maize planted in clumps yielded more grain than conventional row planting; but with higher water availability, equidistant plants in conventional rows produced more grain than the clump planting. Howell et al. (1995) and Schneider and Howell (1998) proposed that slopes of production functions may better represent physiological water use efficiency of grain than either water use efficiency (WUE) or irrigation water use efficiency ratios.

3.6. Tiller production

Data for tillers were not obtained for the 2006 study. However, few tillers were observed probably due to the extreme hot and dry conditions. In 2007, uniformly spaced plants had significantly (P = 0.05) greater numbers of tillers per plant compared with clump planting at all water levels (Table 6). However, there was no significant difference observed between the irrigation methods and their interaction with the planting geometry. Uniformly spaced plants produced approximately two tillers per plant (around 5.1–6.0 tillers m^{-2}) compared with less than one tiller per plant in the clump planting (0.6–0.8 tillers m^{-2}). Studies have shown that reduced tiller number might be due to decreased light interception and lower red to far red ratio at the base of the plant (Krishnareddy et al., 2010). Casal et al. (1986) reported reduction in tillering rate with increasing planting density in Dallis grass (*Paspalum dilatatum*) and Italian grass (*Lolium multiflorum*). Clumped plants in the dense planting geometry may have received less light at the base of the plant compared with individually, uniformly spaced plants. The main stalks produced 16–17 leaves per plant (Table 6). Further, first tillers produced 10–11 leaves and second tillers produced 7–8 leaves per tiller.

3.7. Tiller grain and stover yield

Uniformly spaced plants produced 0.5–3% of the total grain from tillers but 8–10% of the total stover (Table 4) was from tillers. Field observations indicated that many of the tiller ears produced little or no grain. On the other hand, 46%, 42% and 91% of tillers in the clump treatment produced ears under dryland, 50 mm and 100 mm irrigation amounts, respectively, and they contributed 1–2% of grain with 2–5% of the total stover. More tillers from uniformly spaced plants resulted in significantly greater tiller aboveground biomass for equidistant planting compared with clump planting at all irrigation levels. The amount of total aboveground biomass at harvest was significantly higher for clumps compared with uniform planting.

3.8. Leaf Area Index

Leaf Area Index was measured only in 2007. Leaf Area Index increased during the initial 60 days of the growing season for both the clump and row planted treatments. However, uniformly spaced plants produced approximately 19%, 50% and 36% more Leaf Area Index (Fig. 6) during the initial 45 days of growth compared with clumped plants under dryland, 50-mm and 100-mm irrigation levels, respectively. The increased Leaf Area Index for row planting was mainly due to more tillers per plant. Around 70 DAP, Leaf Area Index of the clump plants exceeded the row plants. It will be shown later that equidistant spaced plants utilized more soil water during the early crop growth stages.

3.9. Soil water depletion

The volumetric soil water content (Fig. 7) varied with time of measurement as a result of plant use and seasonal precipitation. Fig. 8 shows the comparison of volumetric soil water at different stages of crop growth between clumps and row planting treatment. These results indicate that clump and uniform plants treatments started the season with the same soil water levels and used similar seasonal amounts of soil water. However, the time of water extraction differed between clump plots and row plots with the clump treatments retaining more soil water during the vegetative growth stages as shown by the amounts of soil water 63 DAP. This difference in soil water results may have been due to the greater LAI for the uniformly spaced plants during the period 45–63 DAP (Fig. 6) and greater leaf temperatures (Figs. 2 and 3). Moreover, uniformly spaced plants produced more tillers compared with clumps, and these tillers used larger quantities of water early in the growing season, resulting in lack of water during the later critical reproductive and grain filling growth stages. This indicates that the clump plants used less soil water compared with the uniformly spaced plants during the first 63 days of the growing season resulting in more soil water being available for grain filling growth stage by the clumped plants.

Additional information on soil water extraction pattern within clumps was obtained (Fig. 9) by comparing the soil water measured by the tube placement between two clumps, i.e., 50 cm from each clump and adjacent tubes placed 17 cm from a clump. More soil water was extracted adjacent to the clumps than 50.8 cm away from the clumps. This might be due to a more uniform or even distribution of roots in the adjacent area.

4. Conclusions

Our results suggest that growing maize in clumps compared with equidistant spacing reduced the number of tillers, early vegetative growth, and LAI. This conserved more soil water for use during the grain filling stage resulting in increased grain yield. The increased yield was primarily due to higher kernel mass and higher Harvest Index values although total aboveground biomass was also higher for the clump treatments. Mutual shading may have played a role in reducing transpiration and plants growing close to each other could have possibly reduced the effect of wind and lowered transpiration rates. Varying the plant geometry may be a useful strategy for growing maize, and possibly other crops, in marginal climatic regions where low plant populations are used and water deficits are common during the grain filling growth stage.

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